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Operational characteristics of a small sewage oxidation lagoon

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OPERATIONAL CHARACTERISTICS

OF A SMALL

SEWAGE OXIDATION LAGOON

BY

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INTRODUCTION

With the rapidly increasing population in the United States the adequate disposal of sewage has become one of the major technical problems which the sanitary engineer has to solve. In most areas it is no longer acceptable practice to discharge domestic sewage or industrial waste products directly into streams or lakes because of the resulting pollution of the water, which may later be used for drinking or recreational purposes. Many larger cities have, therefore, adopted some method of sewage treatment which renders such wastes safe and unobjectionable before they are discharged into a lake or stream. Most of these methods of sewage treatment, however, are very expensive and require the constant attention of trained personnel. The cost of such sewage treatment facilities is usually prohibitive for small towns of one or two thousand population. Even if a town of this size could afford to pay for a treatment plant they could not provide for adequate operation, and a poorly operated sewage treatment plant may create a bigger nuisance than no treatment of the sewage at all.

An important problem, then, is to provide adequate sewage treatment facilities which are especially suited for small towns, camps, or subdivisions. The initial cost of such facilities must be low and the maintenance a minimum. The author believes that sewage oxidation lagoons will, in many cases, be the answer to this problem.

HISTORICAL BACKGROUND AND OBJECT OF THE INVESTIGATION

A sewage oxidation lagoon is an artifically constructed shallow pond which is specifically designed to treat liquid organic wastes by biological stabilization. This stabilization process is a mutually beneficial interaction between bacteria and algae and is taking place constantly in streams and lakes. In sewage lagoons, however, this process is greatly accelerated by providing more nutrients for the algae and by maintaining a liquid depth which is best suited for rapid algae growth and maximum oxygen production. As will be shown later in this dissertation, the amount of available oxygen is directly related to the resulting degree of stabilization.

The lagoon method of sewage treatment in the United States was apparently discovered by accident when sewage was discharged to a shallow basin dug in an old creek bed at Santa Rosa, California, in 1924. The effluent from this basin was found to be entirely satisfactory, and subsequently several California municipalities used such facilities for sewage treatment. The early history and development of oxidation lagoons in California and Texas are described by Gillespie(1), Giesecke and Zeller(2), Caldwell(3), Pearse(4), and others.

(1) Gillespie, C. G., "Emergency Land Disposal of Sewage" - Discussion Sew. Work Jour., 16, 4, 740 (July 1944).

(2) Giesecke, F. E., and Zeller, P. J. A., "Secondary Treatment of Sewage in Artificial Lakes". Eng. News Record 117,674 (1936).

(3) Caldwell, D. H., "Sewage Oxidation Ponds-Performance, Operation and Design". Sew. Works Jour., 18,3,433 (May 1946).

(4) Pearse, L., "Oxidation Ponds: Amer. Pub. Health Assoc. Committee Report". Sewage Works Jour. 20,6,1025 (Nov. 1948)

Lagoons have also been operated successfully at several North Dakota municipalities, and the North Dakota State Health Department recommends and approves this type of sewage treatment. A lagoon put into operation at Fessenden, North Dakota in 1928, for example, is still performing satisfactorily[5]. In spite of these early good results, treatment of

(5) Neel, J. K. and Hopkins, G. J. "Experimental Lagooning of Raw Sewage". Sew. and Ind. Wastes, 28: 1326-1356, 1956.

sewage in Sewage oxidation lagoons did not receive much attention until after World War II. Since that time considerable research has been conducted by the U. S. Public Health Service to determine design criteria which may be used as a guide by engineers who are called upon to design sewage oxidation lagoons. However, since there are still many factors which are not clearly understood about the functioning and operation of these lagoons, the tendency still exists to greatly overdesign them in order to be on the "safe" side.

It is the object of this investigation to determine the maximum possible loading of a small sewage oxidation lagoon and to obtain design and operational criteria for small oxidation lagoons such as might be used for small subdivisions, camps and resorts.

REVIEW OF LITERATURE

The treatment of domestic sewage in sewage oxidation lagoons differs greatly from the treatment of domestic sewage in conventional sewage treatment plants. In order to point out this difference a short review of the operational principles involved in the treatment of domestic sewage in conventional sewage treatment plants follows:

Domestic sewage consists of about 99.8% water and only about 0.2% animal, vegetable and mineral matter. The problem of sewage treatment consists in removing this small amount of organic and mineral matter from the water. This problem is not quite as easy as it sounds because the greater part of the organic matter is in solution, so that it must be removed by some process more complicated than that of simple straining or sedimentation. It is a known fact that organic matter in solution decomposes rapidly in water because it is readily available to microorganisms and their enzymes. The bacteria which are responsible for this decomposition may be classified according to their action into aerobic, anaerobic, or facultative bacteria. Aerobic bacteria require oxygen for their activities; anaerobic bacteria develop when no oxygen is present; and facultative bacteria are active under either condition.

Fresh domestic sewage ordinarily contains some free oxygen 2 to 3 parts per million -[6], and the organic matter is immediately acted on by

(6) Hardenbergh, W. A., "Sewerage and Sewage Treatment" 3rd Ed. p. 227.

the aerobic and facultative bacteria. As soon as the oxygen is used up by combination with other chemicals present, only facultative and anaerobic bacteria can act on the organic matter. Even though these bacteria also contribute to the stabilization of the organic matter in the sewage, this anaerobic phase of the sewage treatment has to be very carefully controlled because the anaerobic bacteria produce putrefactive changes, in which many gases are formed, such as hydrogen (H_2), hydrogen sulfide (H_2S), carbon dioxide (CO_2) ammonia (NH_3), and methane (CH_4), as well as various intermediate compounds of the same products(7).

(7) Ibid, Page 227.

After the domestic sewage enters the sewage treatment plant it is subjected to what is commonly called primary treatment. During this first phase of sewage treatment thesolids in suspension are removed from the sewage by screening and/or sedimentation. The solid material which settles in the settling tank or clarifier is called sludge. It is very odiferous, highly putrescible, and of the consistency of thin mud. Raw sludge is, therefore, very objectionable, and it needs a considerable amount of treatment before it may be safely discharged. The most usual method of treating sludge is by digestion. Digestion is carried on in enclosed tanks, which are usually heated to facilitate the process of digestion. Standard types of sludge digestion tanks are cylindrical in shape with a floating cover and heating coils through which hot water is circulated to maintain a temperature of about 90 degrees Fahrenheit. In the cover, provision is made to collect the gas given off during digestion. This gas is commonly used to heat the water circulated through the tank, and in many plants this gas is used also in gas engines for driving pumps, generators or similar purposes. Many other devices are often used in digestion tanks such as devices for stirring or mixing the sludge to promote digestion, sampling devices, thermometers, gas meters, etc. In the process of digestion water is separated from the sludge. This water is usually called the supernatant liquid and is removed from the digester by a specially designed overflow. The supernatant liquid is turbid and discolored and is usually discharged into the sewer entering the plant. In some instances the supernatant has to be given special treatment because it might interfere with the operation of the plant.[8]

(8) Hardenbergh, W. A., Op. Cit., Page 391.

The sludge has to be stored in the warm digester for a period of from 30 to 45 days. During this time the organic matter in the sludge is converted to stable forms and has few of the characteristics of raw sludge. Digested sludge has a slight musty odor and, since it is of a granular texture and yields water quite readily, it may be dried on sludge drying beds or dewatered by vacuum filters. Open sludge drying beds are the most common means of drying the sludge. About two square feet of area per person contributing sewage to the plant must be provided. The drying process takes from 3 to 4 weeks, the length of time required depending on the character of the sludge, the geographical location, and the weather. Sometimes chemicals are added to speed up the drying process or, if the sludge is to be sold as fertilizer, various mechanical means such as filter presses, centrifuges, mechanical presses, etc., are used.

After primary treatment the free oxygen in the sewage is usually depleted. Because of the large volume of the remaining sewage the removal of the organic matter in solution has to proceed under aerobic conditions. This means that free oxygen has to be made available so that the aerobic and facultative bacteria can continue the stabilization process. This is usually accomplished by filtration or mechanical aeration or by both.

Intermittent sand filtration is the simplest of the methods used for secondary treatment. By this method of treatment, purification is effected in two ways: aerobic bacteria act on the sewage in the interstices of the bed as the sewage passes downward, and some purification is accomplished by the mechanical straining action of the sand. The sewage has to be applied intermittently so that air will always be present in the voids of the filter. A sand filter yields a final effluent which is practically pure and is not subject to decomposition. However, because of the large area of bed required for the treatment of a unit volume of sewage, this method of treatment is not practical for the needs of a municipality.

Mechanical sand filters, rapid sand filters, high rate filters and many other types of filters are used in large sewage disposal plants. They all operate on about the same principle as an intermittent sand filter, but, as the names imply, they are designed to allow a higher rate of application of the sewage and, consequently, less surface area has to be provided for a given amount of sewage.

In the course of secondary treatment, the sewage is oxidized to stable forms which will not further decompose producing odor. The degree to which such oxidation is carried usually depends on local conditions, and the treatment plant is designed accordingly. If the effluent from the treatment plant has to be absolutely safe, that is, be free from all contamination, it may have to be chlorinated before it is discharged into the receiving stream or lake.

As may be seen from the above discussion of a standard sewage disposal plant, the disposal of sewage by these methods is a complicated process. The disposal plant must be very carefully designed, and the constant attention of one or more skilled operators is necessary to insure efficient operation. In order to indicate the sharp contrast between the method of sewage disposal described above and the one in a sewage oxidation lagoon, Figures I and II have been included in this dissertation showing a typical layout of a conventional sewage disposal plant and of a sewage oxidation lagoon respectively.

In a sewage oxidation lagoon the treatment of the domestic sewage is accomplished in one operation under aerobic conditions and without the aid of mechanical means such as pumps, motors, etc. The raw sewage is simply discharged into a shallow lagoon of controlled depth and surface area.

Aerobic bacteria convert the organic carbon contained in the sewage to carbon dioxide. This happens before and during discharge into the lagoon. The resulting environment is favorable for the growth of unicellular organisms known collectively as phytoplankton. These organisms contain chlorophyll and occur in such large numbers that the whole lagoon appears to be green. The phytoplankton are generally classified as algae although some workers consider the flagellated green planktonic forms protozoa. Silva and Papenfuss[9] define algae as "a chlorophyll

(9) Silva, Paul C., and Papenfuss, George F., "A Systematic Study of the Algae of Sewage Oxidation Ponds. SWPCB Publication No. 7, Page 9.

containing unicellular or multicellular organism devoid of conducting tissues, without a morphological differentiation into roots, stems and leaves, and with unicellular reproductive organs". Through photosynthesis these algae convert the CO_2 derived from the bacterial oxidation of organic matter to algal cell material and simultaneously produce a surplus of oxygen beyond their own needs. As reported by Oswald[10] the production of

(10) Oswald, W. J., Gotaas, H. B., et al. Algae Symbiosis in Oxidation Ponds. II Growth Characteristics of Chlorella Pyrenoidosa cultured in Sewage. Sew. and Ind. Wastes, 25: 26-37, 1953.

cell material proceeds according to the simplified photosynthetic equation:

$$2\ CO_2 + 2\ H_2O \xrightarrow{\text{light}} 2\ (CH_2O) + O_2$$

It is generally accepted that, in this reaction, oxygen is derived from the photochemical decomposition of the water molecule, rather than from the splitting of the CO_2 molecule. Oswald[11] terms the substance of the

Figure I

TYPICAL LAYOUT OF A

CONVENTIONAL SEWAGE DISPOSAL PLANT

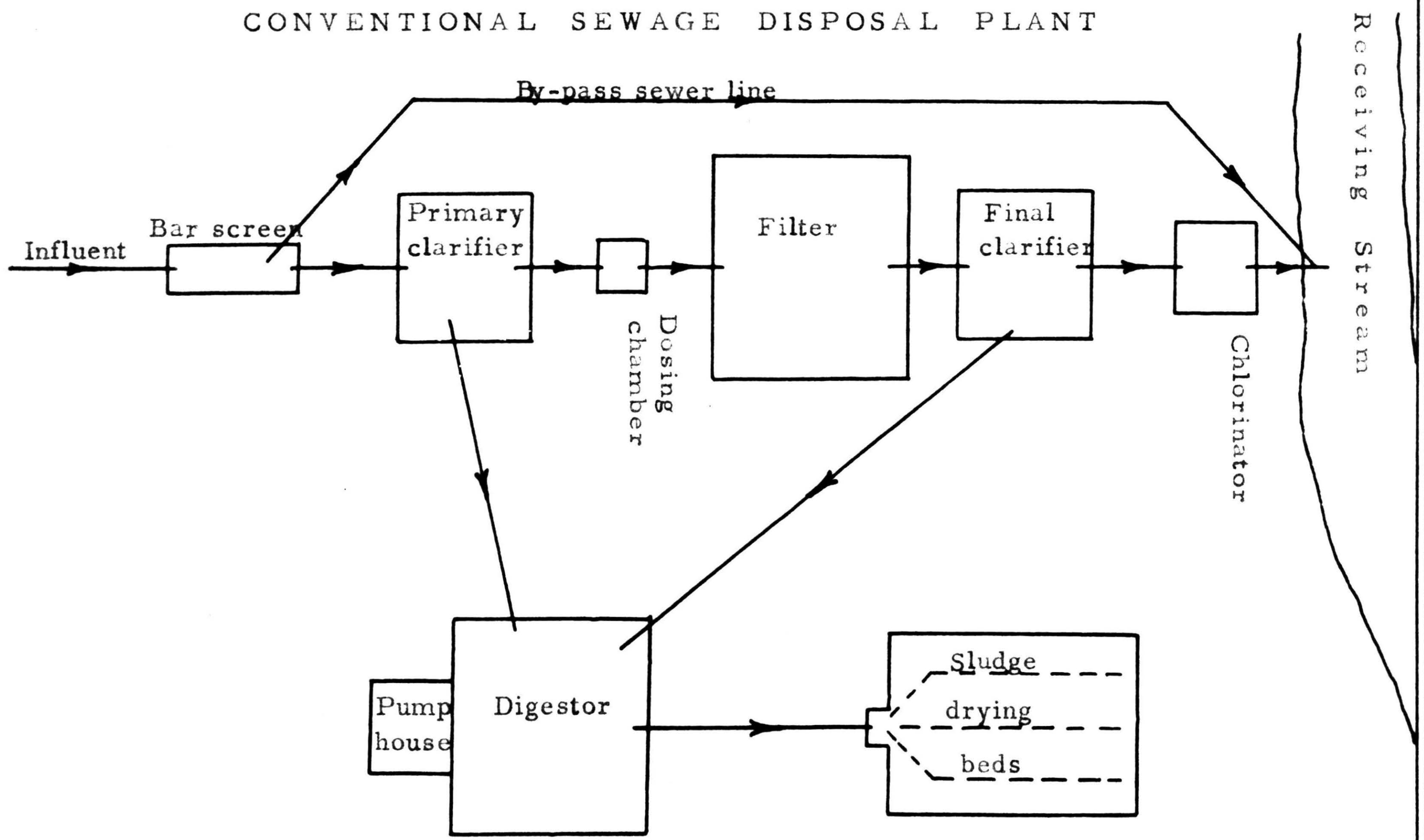
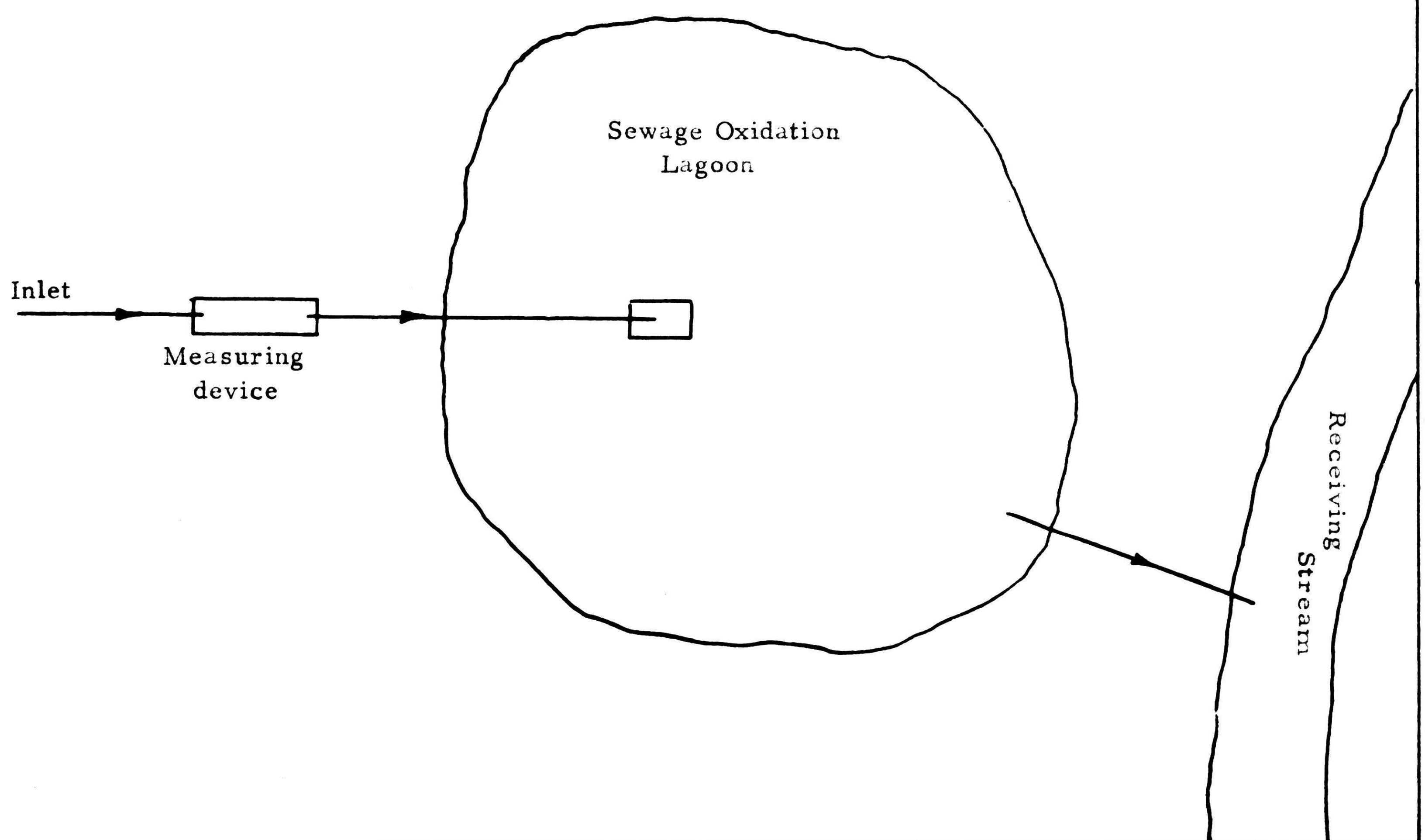


Figure II

TYPICAL LAYOUT OF A

SEWAGE OXIDATION LAGOON



(11) Ibid, Page 26.

general formula CH_2O the "primary cell material". The oxygen is liberated outside the cell and may then serve as the ultimate hydrogen acceptor for bacterial respiration. Thus, water serves as a hydrogen donor for the reduction of CO_2 in algal photosynthesis, and the liberation of oxygen is incidental to the process.

It is this free oxygen which is most important for the proper operation of a sewage oxidation lagoon because aerobic conditions can be maintained only if plenty of free oxygen is available. If the oxygen in the lagoon should become depleted for any length of time, anaerobic conditions would result, and the formation of gases inherent to this condition together with the strong odors would create quite a nuisance. The lagoon must, therefore, be designed in such a way as to promote vigorous algae growth which results in an abundant supply of free oxygen. The State Board of Health of Missouri recommends a maximum depth of 4 feet because sunlight will not penetrate any deeper and without sunlight photosynthesis cannot take place. On the other hand if the lagoon is too shallow aquatic plant growth will result which, if not carefully controlled, will provide ideal breeding places for mosquitos and other insects.

All the lagoons which are now in operation are roughly circular in shape. This design seems to yield the best results because it avoids the forming of stagnant areas. The influent pipe is usually submerged to avoid odors around the influent sewage and is located at approximately the midpoint of the lagoon. The effluent pipe is located as far away from the inlet as possible and discharges the treated sewage from a depth of about 6 inches below the surface of the lagoon into the receiving stream or lake. The banks have a slope of 4:1 and must be kept clean at all times in order to avoid the breeding of mosquitos. This, incidentally, is the only maintenance required for the operation of a sewage lagoon. The size of the pond is determined by the number of people contributing sewage to it. At the present time the State Board of Health of Missouri recommends that one acre of surface area should be provided for every 200 people contributing sewage to the lagoon. This is a new recommendation and has been in effect only since the Fall of 1957. Before that time 1 acre of surface area had to be provided for every 100 people contributing sewage to the lagoon. As will be shown later in this paper, these design data are very conservative, and the lagoons which are now in operation, although they perform very satisfactorily, are not operating at their highest efficiency.

The Sanitary Engineering Laboratories[12] of the University of California made a study of the growth characteristics of a single species of algae, Euglena gracilis, cultured in a sewage environment. Euglena gracilis was chosen for the experiment because it is the predominant species of algae found in oxidation lagoons and is commonly reported as an indicator of pollution in fresh water streams and lakes. The Euglena were grown in the laboratory at a constant temperature of 25 degrees C. in specially designed culture tubes which were subjected to continuous abundant light, and through which air was bubbled upwards to maintain uniform suspension. The retention period was varied from 2 to 20 days. At a retention period of 7 days it was found that the population of the cells were at a maximum, the cells were the smallest and had accumulated very little stored material. Beyond a retention period of 14 days, when some of the nutrients became limiting, the individual cells became more dense indicating that the very old cells stored up products containing less water.

(12) Scientific Monthly, 74: 3-5, 1952. By Harvey F. Ludwig and William J. Oswald.

Comparison of the data indicated that at low retention periods the greater availability of CO_2 resulted in a greater rate of growth, but at high retention periods the organisms were overexposed to CO_2 and suffered injury. Since the production of oxygen is related to synthesis of cellular material, the younger or more rapidly growing cells produce oxygen at a higher rate. The tests showed that young cells photosynthesized much more oxygen than they respired, whereas old cells respired more oxygen than they produced; hence young but not old cells seem to be responsible for the supersaturation of oxygen found in many pond effluents.

Similar tests were conducted by the Sanitary Engineering Laboratories of the University of California using another species of algae, the Chlorella pyrenoidosa. Comparison of the results showed that the "Chlorella" like the "Euglena" remain young and multiply vigorously under a high rate of sewage application corresponding to low retention periods. As the retention period is increased, or the rate of loading decreased, the cells tend to remain in a vigorous multiplying state at the expense of cell size, but eventually, at longer retention periods, an increasing percentage of cells cease to multiply.

These similarities between the "Chlorella" and the "Euglena" are offset by the following differences: "Chlorella" grows more rapidly than "Euglena", entering the various phases at lower retention periods. "Chlorella" tends to autotrophic nutrition, and may decidedly inhibit the saprophytic bacteria necessary to the first stage decomposition of sewage. By inhibiting such bacterial action, "Chlorella" may limit the carbon and nitrogen made available for its continued growth. Also, there is some evidence indicating that certain bacteria may inhibit the "Chlorella" itself. "Euglena" on the other hand, being a facultative saprophyte, appeared to grow better in the presence of sewage bacteria than in sterile sewage. There is no evidence of specific bacterial inhibition by "Euglena Gracilis".

Although there is no direct relationship between the laboratory tube retention period and lagoon retention periods, the following conclusions may be drawn from the results of the above described experiments performed by the Sanitary Engineering Laboratories of California: The retention period in a lagoon should be fixed in such a way as to provide a constant abundant food supply for the algae, and the algae should never be allowed to become old because of the resulting reduction of oxygen production. This stipulation cannot always be met because the algae in a sewage oxidation lagoon are not uniformly distributed but occur in zones of favorable environment. On the fringes of such zones some of the cells might be transferred into palmellar types and, losing motility, would tend to sink to the bottom.

Another aspect of sewage disposal by the lagoon method, the reclamation of the algae from the effluent, has received much attention and study. At the present time all the algae in the existing lagoons are discharged into the receiving stream or lake with the effluent sewage. Actually, the algae cell material is a high-protein food because the algae growing in the lagoon absorb ammonia and other forms of nitrogen from the sewage. They may, therefore, be considered a means for reclaiming waste nitrogen. The commercial possibilities of producing algae food from sewage appears to be good, because the sewage already contains nutrients necessary for growing algae and contains nothing to inhibit their growth. Ludwig and Oswald[13] estimate that the maximum yield of "Euglena" from

(13) Ludwig, H. F., Oswald, W. J., et al. Algae symbiosis in oxidation Ponds. I. Growth Characteristics of Euglena Gracilis cultured in Sewage. Sew. and Ind. Wastes, 23, 1337-1355, 1951.

sewage, fortified with carbon dioxide and subjected to continuous lighting, is 0.26 g per liter of sewage per day. This is about half the yield which has been obtained with "Chlorella" cultured in ideal synthetic media prepared from commercial nutrients. By using a rapidly reproducing algae, such as "Chlorella", therefore, the yields obtained from sewage can probably be increased to some higher limit.

DISCUSSION

In the Spring of 1957, the State Board of Health of Missouri provided funds for the construction of a small sewage oxidation lagoon for the purpose of studying the effect of a high rate of loading with domestic sewage on a lagoon of less than one acre surface area. On the request of the Civil Engineering Department of the Missouri School of Mines and Metallurgy, the Council of the City of Rolla, Missouri, gave permission to build such an experimental lagoon on the plant site of the municipal sewage disposal plant located approximately 3 miles east of the City of Rolla, Missouri.

The experimental sewage oxidation lagoon has a surface area of approximately 0.15 acres at a depth of three feet and is roughly circular in shape. Figure III shows a plat of the location of the experimental lagoon in the municipal sewage disposal plant. The banks have a slope of 4:1 and the outlet pipe is designed so that the depth may be varied from 36" to 70". The lagoon receives raw domestic sewage through a 500 feet long 2" plastic pipe which diverts a part of the influent sewage from Rolla into the lagoon. The discharge end of the pipe was originally anchored to the bottom of the lagoon at the center but, because of operational difficulties, was later allowed to float on the surface of the lagoon. The outlet discharges the treated sewage into Love Creek, a small creek approximately 12" deep and 15 feet wide, which also receives the effluent from the municipal sewage disposal plant through Berger Creek as shown in Figure III. Figure IV shows the method used to divert part of the influent sewage from Rolla into the lagoon. The diversion is made between mechanical bar screen and primary clarifier of the municipal sewage disposal plant. The sewage is picked up after it leaves the mechanical bar screen as the size of the plastic pipe does not allow rags and other large objects to pass through. The mechanical bar screen does not alter the character of the sewage in any way. It merely removes big rocks, rags, sticks, etc., which might interfere with the proper operation of the sewage disposal plant.

When the lagoon was designed, it was expected that the dosing of the lagoon with raw sewage would be varied from 400 people per acre per day to about 800 people per acre per day. This seemed to be a reasonably safe assumption because the State Board of Health of Missouri, North and South Dakota, California and others specified at the time that 1 acre of surface area should be provided for every 100 people contributing sewage to a lagoon. The lagoon was put into operation on July 7, 1957, and the rate of flow of raw sewage into the lagoon was measured to be 8 gpm, which corresponds to a loading of 11,520 gpd or 920 people per acre per day. After two days of loading at this rate, it became obvious that it would take quite a long time to fill the lagoon because of excessive seepage through its bottom and banks. Therefore, it was decided to temporarily increase the flow of raw sewage into the lagoon in order to stop the leakage which amounted to about 50% of loss of the total amount of sewage entering the lagoon. The increase of flow was accomplished by capping the breather pipe (See Table IV) and syphoning the sewage into the pond. This increased the flow to 50 gpm, which corresponds to a loading of 72,000 gpd or 5,750 people per acre per day. By July 18, the depth of sewage in the lagoon had reached the 45" level. Because of faulty operation of the mechanical bar screen the total volume of sewage entering the sewage disposal plant was by-passed several times during the day. This made it impossible to maintain a constant loading of the lagoon until the bar screen was repaired. This was done on July 23, 1957, and from then until

September 7, 1957, the lagoon was dosed 24 hours per day at the rate of 50 gpm or 72,000 gpd. During this period the depth was increased from 45" to 63" and the percent loss due to seepage had decreased to about 20%.

Since absolutely no nuisance conditions developed during the period from July 7 to September 7, the loading of the lagoon was continued at the same rate of 72,000 gpd which, since the depth was kept constant at about 60 inches, corresponds to a loading of 4,800 people per acre per day.

Starting on August 9, dissolved oxygen and hydrogen ion concentration measurements were taken of the effluent and of the pond at various depths. The "Modified Winkler Method" was used for the determination of dissolved oxygen. This method is described in detail in Standard Methods(14).

(14) Standard Methods for the Examination of Water, Sewage and Industrial Wastes, 10th Ed. 1955, Page 252 ff.

Manganous sulfate and alklaline potassium iodide is added to the sample. Manganous sulfide reacts with the potassium hydroxide in the alkaline potassium iodide mixture and produces a white floculent precipitate of manganous hydroxide. If the white precipitate is obtained, there is no dissolved oxygen in the sample. If oxygen is present, it reacts with the manganous hydroxide and forms a brown precipitate of manganic basic oxide. Concentrated sulfuric acid is then added to the sample which dissolves the brown precipitate and forms manganic sulfate. There is an immediate reaction between this compound and the potassium iodide which liberates iodine. The quantity of iodine liberated by these reactions is equivalent to the quantity of dissolved oxygen present in the original sample. The quantity of iodine is determined by titrating a portion of the solution with a standard solution of sodium thiosulfate. The quantity of iodine may also be determined by use of a colorimeter which compares the color of the treated sample with the color of the original untreated sample.

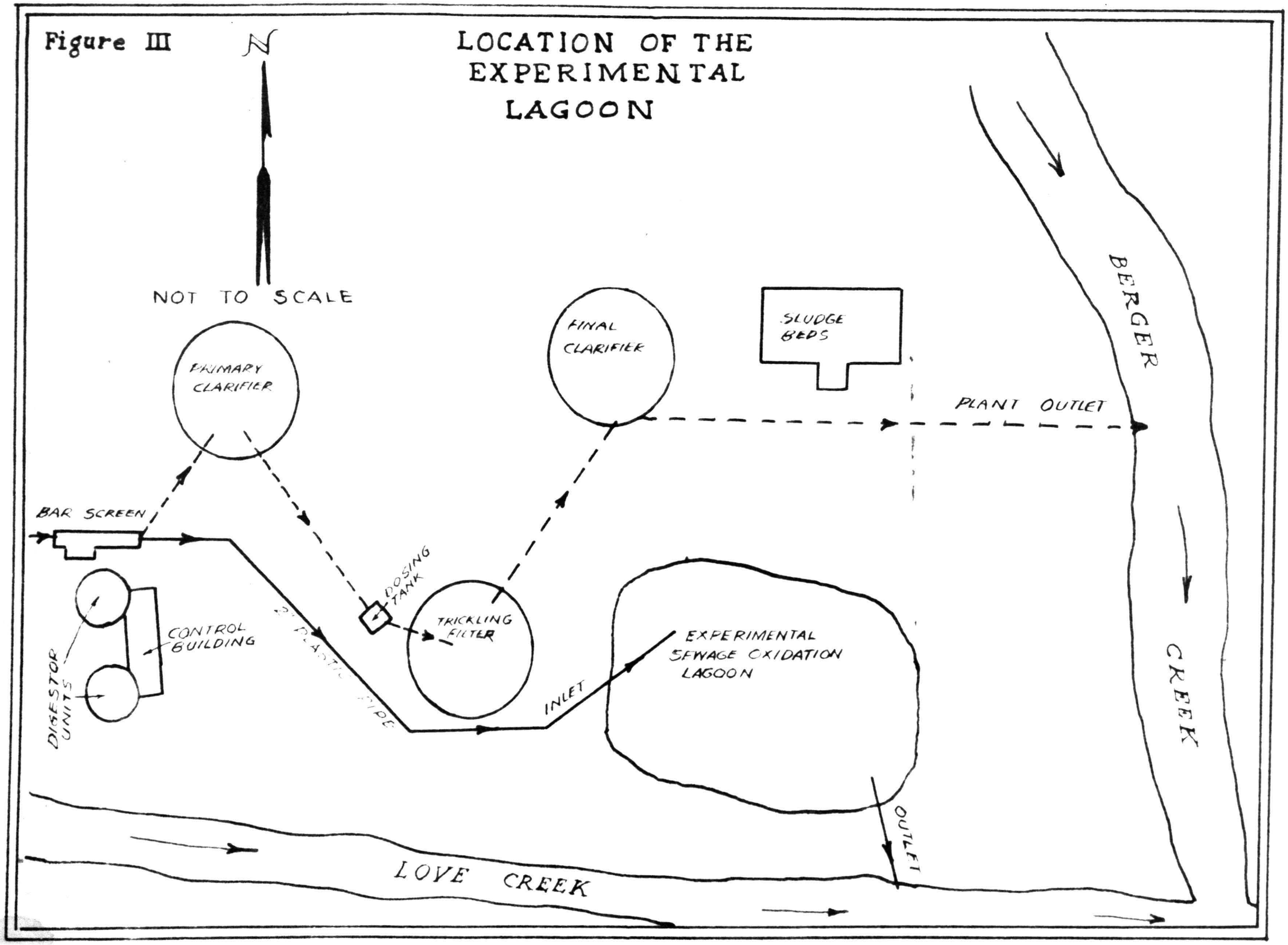
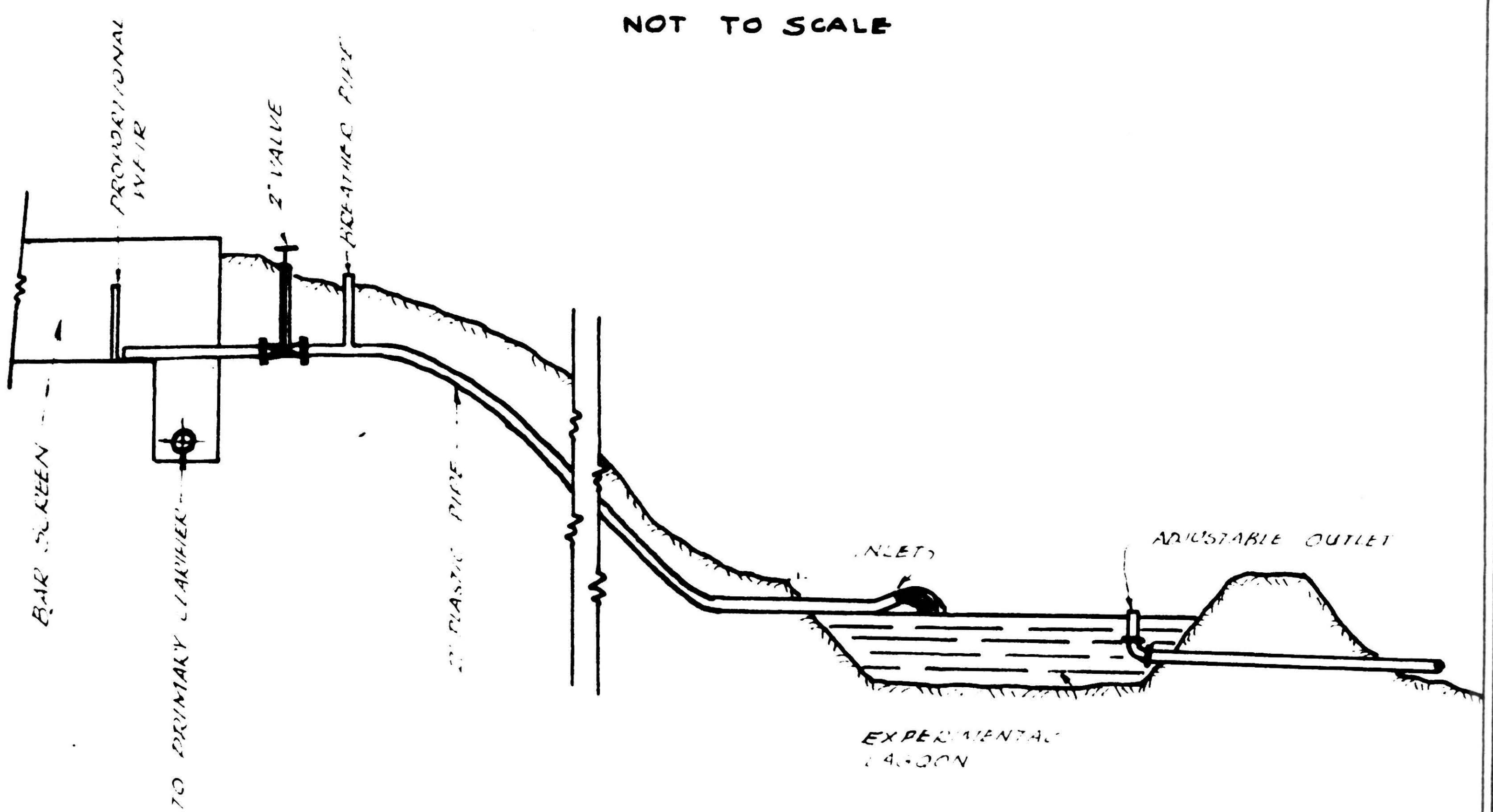


Figure III
LOCATION OF THE EXPERIMENTAL LAGOON
N
NOT TO SCALE
PRIMARY CLARIFIER
FINAL CLARIFIER
SLUDGE BEDS
PLANT OUTLET
BERGER CREEK
BAR SCREEN
DOSING TANK
TRICKLING FILTER
CONTROL BUILDING
DIGESTOR UNITS
INLET
EXPERIMENTAL SEWAGE OXIDATION LAGOON
OUTLET
LOVE CREEK

Figure IV

FLOW DIAGRAM OF THE EXPERIMENTAL LAGOON

NOT TO SCALE



Most of the dissolved oxygen determinations which were made on the lagoon were made with a Hach Colorimeter. Frequent determinations of the accuracy of the Hach Colorimeter were made by checking the results obtained from it against the results obtained from titration with Sodium Thiosulfate. Comparison of the results showed a deviation of less than 5% which was deemed to be sufficiently accurate.

The colorimetric method was also used to determine the P.H. value of the treated sewage. This method makes use of the changes in color which certain dyes undergo under various changes in hydrogen ion concentration. The dyes used as indicators have certain definite P.H. ranges for color change and the indicator selected must be governed by the P.H. of the sample tested. The indicators used for the determination of the P.H. of the experimental sewage lagoon and their respective ranges were:

Brom-thymol blue	6.0 to 7.6
Phenol red	6.8 to 8.4
Cresol red	7.2 to 8.8
Thymol blue	8.0 to 9.6
	(15)

(15) Theroux, Frank R., Eldridge, Edward F., Mallmann, W. LeRoy: "Laboratory Manual for Chemical and Bacterial Analysis of Water and Sewage", McGraw-Hill Book Co., 3rd Ed., Page 147.

The P.H. value of a solution is the logarithm of the reciprocal of its hydrogen ion concentration. It has little bearing on the strength of the sewage, but it indicates whether the sample is acid or basic. P.H. values above 7 indicate an excess of OH^- or an alkaline condition, while P.H. values below 7 indicate an excess of $H+$ or an acid condition. Another reason for determining the P.H. value of the effluent from a sewage oxidation lagoon is that values of P.H. above 7.8 result from photosynthetic activity which removes CO_2 from bicarbonate and produces quantities of monocarbonate. A high P.H. value will, therefore, always coincide with a high quantity of dissolved oxygen in the sample.

From August 9 until October 10, the D.O. of the effluent and the top layers of the lagoon averaged about 8.0 mg/liter on sunny days from 11 a.m. till sundown. (See Table I). During the night the D.O. dropped off to zero and gradually started to build up during the morning hours until it reached its maximum value of about 9.2 mg/1 at about 2 p.m. During cloudy days the D.O. averaged 2 to 3 mg./1. The P.H. increased and decreased very closely with the D.O. with a maximum value of 9.0 and a minimum of 7.6.

It was observed that during the period from August 9 until October 10, there was no dissolved oxygen below a depth of 5" to 6". At a depth of 24" or more the P.H. dropped to about 7.2. Apparently the sewage at a depth of more than 6" was undergoing little, if any, treatment and only the heavy oxygen layer on the surface prevented any odors from escaping. Temperature readings taken of the effluent sewage varied very closely with the air temperature, but at a depth of 2 to 3 feet below the surface of the lagoon the temperature was consistently lower by as much as 4 degrees Fahrenheit. Since it was expected that, because of this stratification and the inadequate treatment of the sewage at lower depths, odors and unsatisfactory effluent would develop during the winter months, it was decided to lower the depth to 56" and to reduce the loading to 24,000 gpd by limiting the inflow of the raw sewage to a few hours per day. A continuous uniform flow at this low rate was not possible because, as mentioned earlier, if the loading must be higher than 1,150 gpd, the sewage has to be syphoned, which is only possible when the pipe is flowing full. This change of loading was put into effect on October 10, 1957.

During the entire period from July 7 to October 10, 1957, there was absolutely no nuisance of any sort connected with the operation of the sewage lagoon even under the high loading of 4,800 people per acre. Over prolonged periods of sunny days a green deposit began to form on top of the lagoon which, at times, covered the entire area of the lagoon. This deposit consisted of dead or dying algae cells which gave off a light musty odor very similar to the odor given off by digested and dried sludge. But, since this odor was noticeable only up to a distance of about 10 feet from the edge of the lagoon, it created no nuisance. This deposit built up much more rapidly when the flow was decreased or stopped completely for a day or two. Wind action during this first observation period was very moderate and there was never any wave action on the lagoon.

The change of loading from 72,000 gpd to 24,000 gpd and the lowering of the water level from 60 inches to 36 inches happened to coincide with the start of a prolonged period of very bad cloudy weather. Heavy cloudiness persisted from October 11 until October 30. Since the sudden lowering of the water level had discharged most of the algae from the lagoon into the receiving creek, and since the production of new algae cell material through photosynthesis proceeded very slowly under the adverse weather conditions the lagoon lost most of its green color and appeared to be gray rather than green. Until October 20, the dissolved oxygen content of the effluent varied from 0.2 to 1.6, and dropped off to zero immediately after sundown. From October 20 until October 30 a light sewage odor was noticeable around the lagoon up to a distance of about 10 feet from the edge of the lagoon, and the dissolved oxygen content seldom rose above zero all day. The first sunny day occurred on November 1, 1957, and by November 3, the odor had completely disappeared and the average dissolved oxygen content was again 8.0 mg/l. Because of a temporary breakdown of the Hach

Colorimeter no more tests were made of the effluent of the lagoon until March 2, 1958. Daily visual inspection of the condition of the lagoon, however, was continued, and the following observations were made:

Around the middle of November a period of bad weather started with heavy dense fog. This condition persisted until the beginning of December with only short interruptions. Whenever the light intensity remained low for a period of more than 6 days a light septic odor was noticeable around the pond. This odor, however, was not discernible from a distance greater than 10 feet from the edge of the lagoon. During periods of sunny weather the lagoon recovered very rapidly, usually within 1 or 2 days, the odor disappeared and the dark green color reappeared. During December long periods of cloudy and rainy weather (one of 18 days duration) followed periods of intermittent sunshine (usually only 2 to 3 days). Again, if any odor developed at all, it was noticeable only up to a distance of about 10 feet from the edge of the lagoon, and the fast recovery during sunny periods was very remarkable.

During the greater part of January, the lagoon and the inlet pipe were frozen solid and thawed out only twice during the month. From January 25 until February 27, the pond was frozen without interruption.

Starting on February 28, the ice cover began to break under milder temperatures and frequent, occasionally heavy, rains. As soon as the influent pipe was free from the ice (March 1, 1958) dosing of the lagoon was started at the rate of 12,000 gpd. This was accomplished by allowing the raw sewage to enter the lagoon at the rate of 50 gpm for a period of 4 hours per day. Sunny weather prevailed from March 1 until March 4. During this period there was absolutely no odor noticeable, the D.O. averaged about 1.0 mg/l and the lagoon had a milky white color. Examination under the microscope of representative samples of the effluent showed that this color may have been caused by algae cells which contained only a very small amount of chlorophyll and appeared to have an almost white color. From March 4 until March 15 the weather was cloudy with occasional light rain or snow flurries, but no odors developed during the entire period even though the dissolved oxygen content was very low, usually around 0.3 to 0.9 mg/l. The color changed to a bluish white with a light tinge of green. Adverse weather conditions prevailed through the remainder of March and through the entire month of April with very few sunny or partly cloudy days during this period (See Table I). In spite of the bad weather, however, the color of the lagoon turned from the bluish white observed at the beginning of the period to a bluish green, a light green and then to a very dark green by March 31.

Starting April 8, 1958, through May and June the dissolved oxygen content of the effluent and the surface layers of the lagoon averaged 8.0 mg/l or above and the P.H. averaged 8.0 or above regardless of weather conditions or rate of loading. The rate of loading was increased to 24,000 gpd on April 16 and then to 72,000 gpd on April 29 until May 21.

Starting on March 31 (when the color of the lagoon became a very dark green) the following observation was made with regard to algae concentration in the lagoon. During cloudy days or whenever the light intensity became very low the very top layers of the lagoon were of a dark green color indicating a heavy concentration of algae in these top layers. On sunny days the top layers of the lagoon were of a light green color or almost clear down to a depth of 12" to 18" depending on the light intensity while the deeper water layers from 12" to about 24" showed a very dark green color indicating a heavy algae concentration at this depth. Dissolved oxygen determinations showed a high content of dissolved oxygen up to a depth of 24". Samples of the effluent sewage from the lagoon in clear bottles were exposed to direct sunlight and to artificial light in the laboratory and the algae in the sample showed the same tendency to avoid light of high intensity by moving away from the direct light. They died off very rapidly when they were not given a chance to avoid the high light intensities, but multiplied vigorously when subjected to artificial or subdued natural light.

On May 4, 1958, the green deposit which was observed during the Fall of 1957 began to form again, and, unless it was removed by heavy rains or driven to one side of the lagoon by wind action, the dissolved oxygen content was low at a depth of 6 inches or more. During the entire observation period very little wave action was observed in the lagoon even though days of moderate to high wind velocities were not uncommon during the Spring of 1958.

Table II shows the results of tests which were made to determine the presence of coliform bacteria in the raw sewage, in the effluent of the lagoon, and in the receiving creek. The results of the tests for coliform bacteria are given as the most probable number (MPN) of coliform bacteria present in 100 ml of the original sample. This test is commonly used to determine the degree of sewage contamination in water. Diseases of intestinal origin, typhoid fever and dysentery particularly, have been and are transmitted by sewage polluted waters. The methods of isolation of the disease causing bacteria are very difficult and not adapted to routine laboratory procedures. The test is therefore made for the presence of the coliform group which are not disease causing bacteria themselves, but which are present in abundance in the intestinal tract of man and animal. Thus the absence of the coliform organisms in a sample of water indicates also the absence of the intestinal pathogens, while the presence of the coliform organisms indicates the possibility that disease causing bacteria are also present. To determine the presence of coliform bacteria in water their ability to ferment lactose with gas formation in nutrient lactose broth is used. Various dilutions of the original sample are added to nutrient lactose broth in fermentation tubes and incubated at 37 degrees Centigrade for a period of 24 to 48 hours and, then, observed for gas formation. This is called the presumptive test. Since there are a few other bacteria, not necessarily of sanitary significance, which may also produce gas from lactose, a confirmed test has to be made. This test consists of incubating a portion of the sample in the fermentation tubes which showed gas formation during the presumptive test in brilliant green bile lactose broth for an additional 24 hours. Only the coliform organisms will form gas in the brilliant green lactose broth. If, therefore, any gas formation is observed during the confirmed test, coliform bacteria are definitely present in the original water sample.

Both the presumptive and confirmed test were used to determine the presence of coliform organisms in the raw sewage, the effluent of the lagoon, and the receiving creek. The most probable number of these organisms was computed with the aid of tables especially prepared for this purpose.(16) The tests were performed at a loading of 72,000 gpd and 24,000 gpd. The results were very consistent and showed that the raw sewage contained about 3,500,000 coliform bacteria per 100 ml of sample while the effluent contained an average of 200,000 to 240,000 coliform bacteria per 100 ml of sample. This represents a reduction of these bacteria of approximately 94.4%. The tests made of the water in the receiving creek approximately 400 feet below the effluent from the lagoon showed a bacteria count of about 15,000 coliform bacteria per 100 ml of sample or a total reduction of 99.6%.

(16) Standard Methods, op. cit., Page 386.

Table III shows the results of tests which were made to determine the biochemical oxygen demand of the raw sewage and of the effluent of the lagoon. The biochemical oxygen demand (BOD) determination is a measure of the oxygen required for the bacteria to oxidize the organic matter in a sample. The test consists of the determination of dissolved oxygen prior to and after a period of incubation at 20 degrees Centigrade. If the oxygen demand of the sample is greater than the available dissolved oxygen, a dilution is made. The period of incubation was chosen at 5 days which is the standard time of incubation for BOD determinations. The 5 day biochemical oxygen demand does not represent the total demand of the sample for oxygen. The percentage of the demand satisfied after the 5 day incubation period is only about 68%[17]. Since it would take

(17) Theroux, Frank R., Eldrich, Edward F., and Mallmann, LeRoy W., "Laboratory Manual for Chemical and Bacterial Analysis of Water and Sewage". McGraw-Hill Book Co., 3rd Ed., Page 178.

an incubation period of 20 days to satisfy 99% of the demand, the 5 day incubation period has become the standard time of incubation. If the total demand is desired it may be calculated by use of tables prepared for this purpose[18]. Two types of samples were used to determine the BOD of the

(18) Ibid, Page 178.

raw sewage and of the effluent of the lagoon, the 24 hour composite sample and the grab sample. For the 24 hour composite sample a small amount of the raw sewage and of the effluent sewage were added to two one-gallon jugs every hour for 24 hours. For the grab sample only one sample of the raw sewage and of the effluent were taken for each test. Dilutions of 1% and 2% were made for the raw sewage and dilutions of 1% and 3% were made for the effluent sewage. The average BOD of the raw sewage was found to be about 250 ppm during dry weather periods and about 180 ppm during wet weather periods. The BOD of the effluent sewage averaged about 57 ppm during both dry and wet weather periods with a high of 115 ppm and a low of 30 ppm. The percent reduction during wet weather periods, therefore, averaged 70% and during dry weather periods 80%.

Since the strength of the raw sewage may be different for different communities the loading of a sewage disposal plant and of a sewage oxidation lagoon is usually given in lbs. of BOD per day. Using the above values of BOD of the raw sewage, which was used in the study of the experimental sewage oxidation lagoon, it is calculated that the lagoon was loaded with 150 lbs. of BOD per day during dry weather periods when loaded at the rate of 72,000 gallons per day and with 108 lbs. of BOD per day during wet weather periods when loaded at this same rate. This corresponds to an average loading of 1,032 lbs. of BOD per acre per day during both wet and dry weather periods. When the lagoon was loaded with 24,000 gpd the loading in lbs. of BOD per acre per day was 400 during dry weather periods and 288 during wet weather periods. At a loading of 12,000 gpd the loading in lbs. of BOD per acre per day was 200 during dry weather periods and 144 during wet weather periods.

TABLE 1

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
8, 9	3 p.m.	3"	88°	86°	Partly Cloudy	12.5	7.6	Dosing at 72,000 Gpd Depth 49"
8, 10	11:30am	2"	85°	86	Sunny	13.4	7.6	Depth 50"
8, 10	3 p.m.	2"	90	88	Sunny	6.0	7.6	
8, 11	2 p.m.	2"	91	99	Sunny	8.0	7.6	
8, 12	10:30 a.m.	4"	90	88	Sunny	0.0	7.6	
8, 13	9 a.m,	6"	80	82	Partly Cloudy	0.0	7.4	Depth 51"
8, 14	1 p.m.	5"	94	90	Partly Cloudy	1.5	7.4	Depth 51"
8, 14	1 p.m.	1"	94	93	Partly Cloudy	8.0	7.8	1/3 of lagoon covered by green deposit
8, 14	3 p.m.	5"	95	93	Partly Cloudy	2.0	7.6	
8, 14	3 p.m.	7"	95	91	Partly Cloudy	0.0	7.4	
8, 14	3 p.m.	1"	95	95	Partly Cloudy	9.0	8.0	

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
8, 15	9 a.m.	1"	87	87	Sunny	7.0	7.8	1/2 of lagoon covered by green dep.
8, 15	9 a.m.	6"	87	86	Sunny	0.0	7.4	
8, 15	11 a.m.	1"	90	90	Sunny	9.2	8.4	
8, 15	11 a.m.	6"	90	88	Sunny	1.3	7.6	
8, 16	9 a.m.	1"	80	79	Sunny	7.0	7.8	Depth 55"
8, 16	9 a.m.	7"	80	78	Sunny	0.0	7.2	
8, 17	11 a.m.	1"	65	65	Cloudy	5.0	7.6	Heavy rainfall during previous night.
8, 17	11 a.m.	8"	65	66	Cloudy	0.0	7.2	Light odor at this depth.
8, 17	4 p.m.	1"	75	75	Partly Cloudy	8.0	7.8	No deposit
8, 17	4 p.m.	8"	75	73	Partly Cloudy	0.0	7.2	Light odor at this depth.
8, 18	11 a.m.	2"	75	74	Sunny	7.2	7.4	Little deposit Depth 49"

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
8, 19	1 p.m.	2"	84	83	Partly Cloudy	13.0	8.2	
8, 19	1 p.m.	6"	84	82	Partly Cloudy	2.2	7.6	
8, 19	4 p.m.	2"	88	87	Partly Cloudy	14.5	8.4	
8, 19	4 p.m.	8"	88	85	Partly Cloudy	1.5	7.5	
8, 20	10 a.m.	2"	70	70	Partly Cloudy	3.0	7.6	30% Deposit
8, 20	10 a.m.	4"	70	73	Partly Cloudy	0.6	7.4	
8, 20	3:30 p.m.	2"	80	80	Mostly Sunny	9.0	8.6	Depth 53"
8,20	3:30 p.m.	5"	80	83	Mostly Sunny	6.2	7.8	
8, 20	7 p.m.	5.5"	75	82	Cloudy	1.0	7.6	
8, 20	7 p.m.	2"	75	78	Cloudy	8.0	8.4	
8, 21	8 a.m.	2"	67	78	Light Rain	1.0	7.4	Depth 55"

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
8, 21	4:30 p.m	2"	72	76	Partly Cloudy	8.0	8.4	
8, 21	4:30 p.m	7"	72	80	Partly Cloudy	1.0	7.6	
8, 22	4:30 p.m	2"	84	84	Sunny	8.0	7.8	Depth 55"
8, 22	4:30 p.m	7"	84	82	Sunny	0.1	7.6	No deposit
8, 23	2:30 p.m	2"	80	80	Sunny	13.0	9.6	
8, 23	2:30 p.m	7"	80	83	Sunny	3.0	8.0	
8, 24	11 a.m.	2"	73	73	Light Rain	9.0	7.8	
8, 24	11 a.m.	9"	73	73	Light Rain	0.6	7.3	
8, 25	11 a.m.	2"	75	75	Sunny	9.0	7.8	
8, 25	11 a.m.	11"	75	82	Sunny	0.1	7.1	
8, 25	6 p.m.	12"	84	82	Sunny	1.8	8.1	

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
8, 25	6 p.m.	2"	84	82	Sunny	13.0	8.2	
8, 26	9 a.m.	2"	77	81	Sunny	10.0	8.0	75% Deposit
8, 26	9 a.m.	11"	77	81	Sunny	0.1	7.3	
8, 27	9 a.m.	3"	78	78	Sunny	0.2	7.6	100% Deposit Depth 53"
8, 27	4 p.m.	2"	93	90	Cloudy	0.2	8.1	Very humid
8, 28	10 a.m.	2"	80	80	Cloudy	12.5	9.0	Changing moderate to heavy winds. 50% to75% Deposit.
8, 28	10 a.m.	5"	80	80	Cloudy	0.8	7.7	
8, 28	2:30 p.m.	3"	82	82	Cloudy	3.8	8.2	100% Deposit No wind.
8, 28	2:30 p.m.	6"	82	82	Cloudy	0.1	7.8	
8, 29	10 a.m.	2"	80	80	Sunny	2.0	7.5	50% Deposit Light wind.
8, 29	10 a.m.	9"	80	80	Sunny	0.8	7.5	

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
8, 29	4 p.m.	3"	88	86	Sunny	12.0	8.4	50% Deposit Light Wind.
8, 29	4 p.m.	7"	88	86	Sunny	1.2	7.5	
8, 30	4 p.m.	2"	92	88	Partly Cloudy	10.5	8.5	
8, 30	4 p.m.	12"	92	88	Partly Cloudy	0.1	7.9	
8, 31	11:30 a.m	2"	88	86	Sunny	6.0	8.1	
8, 31	11:30a.m	4"	88	86	Sunny	2.6	7.6	
9, 1	3:30 p.m.	2"	78	80	Cloudy	12.0	9.0	Depth 57" Very little deposit.
9, 2	3:30 p.m.	2"	80	88	Partly Cloudy	13.0	9.2	
9, 3	2:30 p.m.	2"	80	88	Sunny	14.0	10.5	
9, 3	2:30 p.m.	5"	80	88	Sunny	14.0	10.5	
9, 4	2 p.m.	2"	75	80	Partly Cloudy	7.0	8.3	

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
9, 5	2 p.m.	2"	69	74	Heavy Cloudiness	2.0	7.7	Outlet stopped up depth 63"
9, 7	2 p.m.	2"	68	69	Cloudy Rain	0.7	7.6	Depth 58"
9, 9	2 p.m.	2"	70	72	Cloudy	1.2	7.7	Start dosing at 24,000 Gpd.
9, 10	3:30 p.m.	2"	76	80	Sunny	10.0	8.6	
9, 11	2:30 p.m.	2"	78	78	Partly Cloudy	10.0	10.0	90% Deposit
9, 12	1 p.m.	2"	72	74	Cloudy	0.0	8.0	
				1958				Dosing at 12,000 Gpd.
3,2	2 p.m.	2"	32	32	Cloudy	0.0	7.6	Milky white color Depth 34", light odor
3, 3	3 p.m.	2"	37	36	Sunny	0.9	7.2	Milky white color Depth 34", light odor
3,4	2 p.m.	2"	55	55	Sunny	0.4	7.2	NoOdor
3, 5	2 p.m.	2"	44	44	Heavy Cloudiness	0.0	7.3	Depth 35", white color No odor.

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
								3,5 to 3, 10 no tests because of rain & snow
3, 11	1 p.m.	2"	38	38	Cloudy	0.35	6.7	No odor, white color
3, 12	1 p.m.	2"	47	47	Cloudy	0.0	7.6	Bluish-white color No odor.
3, 13	4 p.m.	2"	45	45	Cloudy	0.0	7.5	Bluish-white color No odor.
3, 14	10 a.m.	2"	36	36	Cloudy	0.35	6.7	Bluish-white color No odor.
3, 15	2:30 p.m.	2"	52	52	Sunny	0.1	7.7	1st day of sunshine since 3, 4, 58
3, 16	2 p.m.	2"	48	48	Cloudy	0.3	7.7	No odor, light green tinge appears.
3, 17					Snowing			Snow storm, no observation.
3, 18	2 p.m.	2"	44	44	Sunny	1.8	7.8	Light intensity magnified by snow on banks of lagoon.
3, 19	2 p.m.	2"	48	48	Snow Flurries	1.0	7.6	Bluish-white color No odor.
3, 20	2 p.m.	2"	40	40	Snow Flurries	0.3	7.5	

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
3, 21	1:30 p.m.	2"	50	51	Sunny	1.5	7.6	Bluish green color, No odor.
3, 22	to 3, 24				Snow & Rain			No observation
3, 25	1 p.m.	2"	42	42	Cloudy	0.7	7.0	Light green color No odor
3, 26	1 p.m.	2"	48	48	Partly Cloudy	1.0	7.2	
3, 27	1 p.m.	2"	50	50	Cloudy	1.0	7.0	
3, 28	1 p.m.	2"	58	57	Sunny	2.2	7.4	Light green color, No odor.
3, 31	1 p.m.	2"	65	63	Sunny	1.7	7.2	Green Color
4, 1	2 p.m.	2"	69	68	Cloudy	3.4	7.4	
4, 2	1 p.m.	2"	80	78	Sunny	3.6	7.5	
4, 8	1 p.m.	2"	63	63	Sunny	12.2	8.15	Grass-green color No odor.
4, 9	11 a.m.	2"	60	61	Cloudy	11.0	8.2	Grass-green color No odor.

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
4, 10	1 p.m.	6"	64	64	Partly Cloudy	6.0	7.8	
4, 10	1 p.m.	18"	64	64	Partly Cloudy	6.4	7.9	
4, 11	2 p.m.	6"	65	65	Sunny	8.0	8.0	Very dark green color
4, 11	2 p.m.	18"	65	65	Sunny	4.0	8.0	Very dark green color
4, 13	10 a.m.	6"	58	59	Cloudy	4.0	7.9	
4, 13	10 a.m.	20"	58	60	Cloudy	4.0	7.9	
4, 14	4 p.m.	8"	55	55	Cloudy Rain	10.0	8.0	Light green effluent
4, 14	4 p.m.	18"	55	55	Cloudy Rain	9.5	8.0	Dark green effluent
4, 15	1 p.m.	6"	60	59	Partly Cloudy	12.0	8.2	Clear effluent
4, 15	1 p.m.	20"	60	59	Partly Cloudy	7.0	7.8	Dark green effluent
4, 16	2 p.m.	6"	75	74	Sunny	14.0	8.0	Clear effluent

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
4, 16	2 p.m.	20"	75	75	Sunny	12.0	8.2	Dark green effluent
			Dosing at 24,000 GPD.					
4, 17	1:30p.m	6"	82	80	Sunny	16.2	9.5	Light green color
4, 17	1:30 p.m.	20"	82	80	Sunny	10.35	9.0	Dark green color
4, 18	3 p.m.	6"	85	85	Cloudy	15.3	9.8	Light green color
4, 18	3 p.m.	24"	85	83	Cloudy	9.0	8.8	Dark green color
4, 21	1 p.m.	6"	64	66	Cloudy Rain	9.2	8.6	Green color
4, 21	1 p.m.	24"	64	66	Cloudy Rain	8.1	8.0	Green color
4, 22	10 a.m.	6" to 24"	60	60	Sunny	10.1	9.4	Dark green color
4, 24	7 p.m.	6" to 24"	60	60	Sunny	11.5	9.0	Green deposit. Light odor at a depth of 20"
4, 25	12 noon	6" to 24"	50	50	Partly Cloudy	12.5	9.1	100% deposit

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
4, 26	12 noon	6"	47	49	Cloudy Rain	6.0	8.0	
4, 26	12 noon	20"	47	50	Cloudy Rain	2.0	7.8	
4, 28	2 p.m.	6" to 30"	50	50	Sunny	12.0	9.2	No green deposit
				Dosing at 72,000 Gpd.				
4, 29	1 p.m.	6" to 30"	48	47	Sunny	12.0	9.0	
5, 1	1:30p.m	6"	60	59	Sunny	14.2	9.6	
5, 1	1:30 p.m.	30"	60	59	Sunny	9.0	8.6	
5, 2	1 p.m.	8"	75	75	Cloudy Rain	6.0	8.3	
5, 2	1 p.m.	2"	75	75	Cloudy Rain	7.0	7.9	
5, 6	3 p.m.	6"	58	57	Sunny	14.2	10.2	
5, 7	1 p.m.	6"	65	65	Sunny	12.5	9.6	

TABLE 1 (Cont.)

Date	Time	Sampling Depth	Air Temp. F	Water Temp. F	Weather	D.O.	P.H.	Remarks
5, 7	1 p.m.	36"	65	65	Sunny	0.22	7.4	Light sewage odor
5, 9	1 p.m.	6"	70	70	Partly Cloudy	12.2	8.7	
5, 9	1 p.m.	30"	70	70	Partly Cloudy	7.5	7.4	
5, 10	1 p.m.	6"	68	68	Cloudy	12.3	8.7	
5, 10	1 p.m.	24"	68	68	Cloudy	7.0	7.4	
5, 11	10 a.m.	2"	74	72	Sunny	12.0	8.8	Dark green color
5, 11	10 a.m.	20"	74	74	Sunny	1.8	7.4	Light sewage odor
5, 12	2 p.m.	0-24"	80	80	Sunny	12.4	9.1	
5, 13	1 p.m.	6"	80	82	Sunny	10.5	8.3	
5, 15	3 p.m.	6"	80	78	Cloudy Rain	10.1	9.0	
5, 16	2 p.m.	6"	85	85	Mostly Cloudy	12.0	9.3	

TABLE 2

Sampling Date	Time	Weather	Ave. weather conditions during 5 days prior to date	Raw BOD	Effluent BOD	% Red	Remarks
10, 23 1957	3 p.m.	Cloudy	Heavy cloudiness Ave. Temp. 65°	258	104	60%	Light sewage odor from lagoon.
11, 18 1957	24 hr. composite	Cloudy	Heavy cloudiness and fog. Ave. temp. 48°	250	115	54%	Septic odor
11, 19 1957	24 hr. composite	Cloudy	Heavy cloudiness and fog. Ave. temp. 48°	142	80	44%	Raw sewage diluted by heavy rainfall.
11, 20 1957	24 hr. composite	Sunny	Heavy cloudiness and fog. Ave. temp. 48°	200	90	55%	No odor
11, 21 1957	24 hr. composite	Sunny	Partly cloudy Ave. temp. 38°	250	70	72%	No odor
11, 22 1957	24 hr. composite	Cloudy	Partly cloudy Ave. temp. 38°	212	66	69%	No odor - freezing
11, 23 1957	24 hr. composite	Cloudy	Partly cloudy Ave. temp. 32°	210	60	71.5%	Lagoon half covered with ice.
11, 24 1957	---	---	----	--	--	--	Lagoon completely covered with ice.
3, 18 1958	10 a.m. to 4 p.m.	Partly Cloudy	Mostly cloudy. Ave. Temp. 40°	280	50	82%	No odor
3, 19 1958	10 a.m. to 4 p.m.	Cloudy Snow Flurries	Mostly cloudy. Heavy snow on March 17 - Ave. Temp. 38°	190	50	74%	Raw sewage diluted by snow melt.
3, 20 1958	10 a.m. to 4 p.m.	Cloudy Snow Flurries	Mostly cloudy. Heavy snow on March 17 - Ave. Temp. 48°	190	60	68.5%	No odor

TABLE 2 (Cont.)

Sampling Date	Time	Weather	Ave. Weather conditions during 5 days prior to date	Raw BOD	Effluent BOD	% Red	Remarks
3, 21 1958	10 a.m. to 4 p.m	Sunny	Mostly cloudy with occasional snow - Ave. Temp. 36°	210	60	71.5%	
3, 25 1958	10 a.m. to 4 p.m	Cloudy	Mostly cloudy with occasional rain or snow Ave. Temp. 38°	180	30	83.5%	Raw sewage diluted by rain and snow melt. No odor
3, 28 1958	10 a.m. to 4 p.m.	Sunny	Mostly cloudy with occasional rain or snow Ave. Temp. 38°	200	45	77.5%	No odor
4, 8 1958	10 a.m. to 4 p.m.	Sunny	Partly Cloudy Ave. Temp. 50°	250	40	84%	Grass green color No odor
4, 10 1958	10 a.m. to 4 p.m.	Partly Cloudy	Partly Cloudy Ave. Temp. 50°	280	50	82%	Very dark green color No odor
4, 15 1958	3 p.m.	Partly Cloudy	Partly Cloudy Ave. Temp. 50°	240	40	83.5%	
4, 22 1958	8 a.m. to 4 p.m.	Sunny	Partly Cloudy Ave. Temp. 60°	250	40	84%	Dosing at 24,000 Gpd since 4, 16
5, 1 1958	24 hr. composite	Sunny	Partly Cloudy Ave. Temp. 45°	240	50	79%	Dark green color No odor.
5, 2 1958	24 hr. composite	Cloudy	Partly Cloudy Ave. Temp. 45°	240	45	81%	Dosing at 72,000 Gpd since 4, 28
5, 10 1958	24 hr. composite	Cloudy	Mostly sunny Ave. Temp. 55°	260	50	81%	
5, 17 1958	2 p.m.	Sunny	Mostly sunny Ave. Temp. 70°	230	30	87%	

TABLE 2 (Cont.)

Sampling Date	Time	Weather	Ave. Weather Conditions during 5 days prior to date	Raw BOD	Effluent BOD	% Red	Remarks
5, 31 1958	24 hr. composite	Sunny	Mostly Sunny Ave. Temp. 70°	250	60	76%	Loading at 24,000 Gpd since May 21, 1958
6, 11 1958	3 p.m.	Sunny	Mostly Sunny Ave. Temp. 70°	240	30	87.5	

TABLE 3

Sampling Date	Time	Sampling Point	Weather	Ave. Weather Conditions during 5 days prior to date	MPN	% Red	Remarks
3, 18 1958	10 a.m. to 4 p.m.	Inlet	Partly Cloudy	Mostly cloudy - Ave. Temp. 40°	3,500,000		Dosing at 12,000 Gpd
3, 18 1958	10 a.m. to 4 p.m.	Outlet	Partly Cloudy	Mostly cloudy - Ave. Temp. 40°	250,000	93%	Dosing at 12,000 Gpd
3, 20 1958	3 p.m.	Inlet	Cloudy Snow Flurries	Mostly cloudy - heavy snow on March 17	2,900,000		Dosing at 12,000 Gpd
3, 20 1958	3 p.m.	Outlet	Cloudy Snow Flurries	Mostly cloudy - heavy snow on March 17	150,000	95%	Sewage diluted by snow melt.
3, 20 1958	3 p.m.	Creek	Cloudy Snow Flurries	Mostly cloudy - heavy snow on March 17	14,000	99.5%	Dilution by creek Water
4, 22 1958	8 a.m. to 4 p.m.	Inlet	Sunny	Partly Cloudy Ave. Temp. 60°	3,900,000		Dozing at 24,000 Gpd
4, 22 1958	8 a.m.to 4 p.m.	Outlet	Sunny	Partly Cloudy Ave. Temp. 60°	2,000,000	95%	
4, 22 1958	8 a.m.to 4 p.m.	Creek	Sunny	Partly Cloudy Ave. Temp. 60°	15,000	99.6%	
5, 16 1958	24 hr. composite	Inlet	Mostly Cloudy	Mostly Sunny - Ave. Temp. 70°	3,900,000		Dosing at 72,000 Gpd
5, 16 1958	24 hr. composite	Outlet	Mostly Cloudy	Mostly Sunny - Ave. Temp. 70°	2,30,000	94%	
5, 16 1958	24 hr. composite	Creek	Mostly Cloudy	Mostly Sunny - Ave. Temp. 70°	15,000	99.6%	

CONCLUSIONS

The results of the experiments conducted on a small sewage oxidation lagoon indicate clearly that the treatment of domestic sewage in a small oxidation lagoon is not only feasible but also very economical and efficient. The dissolved oxygen determinations show that the oxygen production of the algae cells during the day exceeds by far the amount of oxygen needed by the algae themselves and quite often the production of oxygen proceeds at such a rapid rate that some of the oxygen produced cannot be dissolved in the water but must escape into the atmosphere. Comparison of the results of the D.O. determinations and the corresponding water temperatures as given in Table I with a table of the solubility of oxygen in water shows that the condition of the lagoon effluent was quite often one of super-saturation with oxygen with respect to the atmosphere. This may explain the fact that there was no odor noticeable around the lagoon, not even around the influent raw sewage which entered the lagoon through the air as shown in Figure IV, Page 20.

BOD determinations are the criterion by which the quality of the effluent of standard sewage disposal plants is determined. The effluent of a well designed and properly operated standard sewage disposal plant will usually have a BOD of from 15 to 20 ppm which, depending on the strength of the raw sewage, represents a reduction of from 88% to 91%. Compared with these figures the effluent obtained from a sewage oxidation lagoon is not very good. However, as will be shown in the following discussion, BOD determinations of the effluent from a sewage oxidation lagoon is not a good criterion by which this effluent may be judged.

During the treatment of sewage in a standard sewage disposal plant practically all of the organic matter originally present in the raw sewage has to be either removed or oxidized to stable forms which will not require any more oxygen after their discharge into the receiving stream. This is a very important factor which must be considered in the design of any type of sewage disposal plant because if the effluent from the plant has a high oxygen demand it may deplete the dissolved oxygen in the receiving stream which would obviously have a very bad effect on the fish and other aquatic life forms in the receiving stream. Because of the entirely different type of sewage treatment in a sewage oxidation lagoon this problem does not arise when the treated sewage from a lagoon is discharged into a stream. As was stated earlier the algae in a lagoon, through photosynthesis, convert much of the carbon dioxide produced by bacterial action to algal cell material. Since the algae are discharged with the treated sewage, the lagoon effluent may contain a large amount of organic material. Whereas the entering sewage solids are highly putrescible and hazardous to the public health, the algae cells in the effluent are very stable and have no pathogenic significance. When a sample of this effluent is subjected to the BOD test the algae will be killed during the incubation period and will, therefore, increase the biochemical oxygen demand of the sample. However, when the algae are discharged into the receiving stream the condition of the stream determines what will happen to them. If the stream itself is polluted or if there is still some pollution in the effluent, the algae cells will remain young and produce an abundant supply of oxygen which makes it possible for the bacteria to complete the stabilization process. Only when there is no more pollution in the stream will the algae cells grow old and create a slight oxygen demand which will, then, have no more significance.

During the operation of the experimental sewage oxidation lagoon it was observed that the receiving creek maintained the dark green color of the effluent up to a distance of about 500 feet downstream where it changed to a light green color. When the municipal sewage treatment plant broke down temporarily because of a break in a pipe and the sewage received very little treatment by the plant, the color of the creek below the point where the effluent from the plant enters Love Creek (See Figure III, Page 19) turned a dark green indicating that the algae were again reproducing rapidly, and that the sewage received some treatment after it was discharged.

It was also observed that a great number of minnows and other small fish gathered around the effluent of the lagoon apparently feeding on the discharged algae. It was not attempted to stock any fish in the lagoon itself but after it had been in operation for about a month quite a few frogs started to live in and around the lagoon. The fact that so many small fish were attracted to the effluent of the lagoon seems to indicate that the effluent from a lagoon, even if its BOD is rather high, is not only not harmful to the receiving stream but may even be beneficial in sustaining fish and other wildlife.

Deposition of sludge around the banks and on the bottom of the lagoon averaged about 0.2 inches over the 10 month period during which the experimental lagoon was in operation. This indicates that the accumulation of sludge would not create any problem in the operation of a lagoon. Loss of sewage due to seepage and percolation was practically non-existent after March, 1958. Apparently, sewage solids, together with loose sand and clay particles succeeded in sealing the bottom and the banks of the lagoon during the 8 month period of operation.

Unfortunately no data could be obtained during most of the winter month because the lagoon could not receive any more raw sewage since the influent pipe was frozen. This problem of freezing of the influent pipe would not exist in a regular sewage oxidation lagoon because vitrified clay pipe of at least 8" diameter would be used for the outfall line, and this outfall line would have to be covered by at least 2 to 3 feet of ground. Because of economic reasons the influent pipe to the experimental sewage lagoon was only 2" in diameter and had an earth cover of only about 3 to 4 inches and, probably most important of all, it was carrying sewage for only about 4 hours per day and had to remain full whenever the flow was stopped since the syphon had to be maintained.

The only conclusion which can be drawn about the operation of the experimental sewage lagoon during the winter month is that, while it was in operation, there was no nuisance condition connected with it. It stands to reason to assume that the treatment of sewage in a lagoon under an ice cover has to proceed under anaerobic conditions since little, if any, photosynthetic action can take place. The odors connected with this anaerobic condition, however, would be confined to the lagoon and little, if any, odor would escape to the atmosphere. The critical period, then, would be the change from anaerobic to aerobic conditions when the ice melts. No nuisance was connected with this change over in the experimental sewage oxidation lagoon, but this may be due to the fact that no more sewage had been added to the lagoon for over a month prior to the thawing out process. Reports from most lagoons which are now in operation in the State of Missouri indicate that this period of change from aerobic to anaerobic conditions creates odors which are noticeable for considerable distances from the edge of the lagoon. These nuisance conditions usually prevail for a period of from 8 to 14 days. Experiments are now underway to determine whether the addition of certain chemicals which liberate oxygen when dissolved in water will speed up this recovery process.

According to the theory about the operation of sewage oxidation lagoons and according to the results obtained from the experimental lagoon a depth of about 3 feet will yield the best results when the treatment of the sewage proceeds under aerobic conditions. The relatively few data obtained during the short period of operation of the experimental sewage oxidation lagoon are not sufficient to make definite recommendations as to the rate of loading of such a lagoon. It seems obvious to the author, however, that the lagoons which are in operation at the present time are greatly over-designed. They are generally being loaded at the rate of 17 lbs. of BOD per acre per day while the experimental lagoon operated very satisfactorily at the rate of 1,032 lbs. of BOD per acre per day during the summer month and at the rate of 344 lbs. of BOD per acre per day during the winter months in which it was in operation. The lagoons now in operation accomplish a removal of BOD of approximately 80% during the summer months and 55% to 60% during the winter months and(19) a removal of coliform bacteria of more than 99.8%. The algae concentration in the effluent of these lagoons is approximately 100,000 of the predominant species per ml of sample. The laboratory of the State Board of Health of Missouri conducted a test of the effluent of the experimental lagoon when it was loaded at the rate of 1,032 lbs. of BOD per acre per day and found a concentration of the predominant species of algae chlamydomonas of over 900,000 per ml of sample. This high concentration of algae cells at the high loading of 1,032 lbs. of BOD per acre per day indicates that if more food is available algae will produce more rapidly and will be present in greater numbers. Considering the greater number of algae in the effluent the BOD removal accomplished by the experimental lagoon compares favorably with

(19) SED Research Report, Journal of the Sanitary Engineering Division, Volume 84, No. SA 3, June, 1958.

the removal accomplished by other lagoons loaded at a much lower rate of loading. The removal of coliform bacteria in the experimental lagoon averaged only about 94.4% at the effluent but at a point 400 feet below the effluent the coliform bacteria count was within reasonable limits. If a greater removal of coliform bacteria is required in an actual installation it would be a simple matter to fence in a portion of the receiving stream up to a point where the water may be considered safe enough for public use. This, however, may not be necessary because standard sewage disposal plants do not accomplish a reduction in coliform bacteria of more than 95%.

RECOMMENDATIONS

The object of this investigation is to determine the maximum possible loading of a small sewage oxidation lagoon and to obtain design and operational **criteria** for small oxidation lagoons such as might be used for small subdivisions, camps and resorts. The actual maximum possible loading of the experimental sewage oxidation lagoon used for this investigation could not be determined because it performed satisfactorily under the highest rate of loading which was possible with the small influent pipe. The conclusion may be drawn, therefore, that a small sewage oxidation lagoon, which would be in operation during the summer months only, will treat raw sewage adequately at least up to a loading of 1,000 lbs. of BOD per acre per day or 5,000 people per acre per day. Such a lagoon would be adequate for camps, summer resorts, country clubs and similar places.

A maximum loading of 100 to 150 lbs. of BOD per acre per day or 600 to 800 people per acre per day may be permissible for a sewage oxidation lagoon which is to be in operation all year such as may be used for a small subdivision. This design, however, should not be used until more research has been done to determine the operation of a sewage oxidation lagoon during the winter months.

The circular shape yielded good results with the experimental lagoon and is recommended for similar installations. The influent pipe should be located at approximately the third point farthest away from the outlet and should be anchored at the bottom of the lagoon. It is recommended that the effluent pipe is made larger than the influent pipe and located so that only half of it is submerged under the water. This type of outlet will discharge only the top layers of the lagoon, which contain the most dissolved oxygen and received the best treatment, and will also skim off some of the green deposit which was observed to form during prolonged periods of sunny and dry weather.

The author wishes to make the following recommendations concerning further research on sewage oxidation lagoons. Experimental sewage oxidation lagoons similar to the one used for research by the Missouri School of Mines and Metallurgy should be kept in operation for a period of at least two years and should be loaded at the rate of about 1,000 lbs. of BOD per acre per day. It may be expected that these experimental lagoons will perform satisfactorily during the spring, summer and fall months if operated at a depth of about 3 feet. If trouble develops during the winter months sodium nitrate or a similar substance which will liberate oxygen when dissolved in water should be added to the lagoon. The effect of the addition of these chemicals and the amount added should be carefully studied and evaluated. If this method of maintaining aerobic conditions during the winter months appears to be too costly the feasibility of increasing the retention period by increasing the depth of the lagoon may be studied. If treatment of the sewage proceeds under anaerobic conditions an increase in the depth of the lagoon would not affect the treatment adversely, but the increased detention period may produce an acceptable effluent. In certain regions of the country where water is very scarce, it may be desirable to use the effluent of lagoons for irrigation purposes. If this is the case, losses due to evaporation must be kept at a minimum which may be accomplished by building 2 or 3 lagoons in series and treating the sewage in only one of the lagoons during the summer months or as long as a satisfactory effluent is produced. When trouble develops the raw sewage may be distributed in all of the lagoons provided,thus increasing the surface area and the detention period.

Another phase of the research should be concerned with the use of artificial light to increase the efficiency of a lagoon. Part of this study would consist of the use of **artificial** light on aquariums containing raw sewage. This could be done in the laboratory and the desirable light intensity and wave length of the light could be determined. Lights should also be placed around the experimental lagoon. The lights would be controlled by an electronic eye which turns them on or off as the natural light drops below or rises above a predetermined intensity.

It is the opinion of the author that the importance of sewage oxidation lagoons will increase in the future when methods for the removal of the algae from the effluent have **bemn** perfected. Algae are a high protein food which may be used for feeding cattle as mentioned earlier and Ludwig and Oswald[20] found that algae cells may pick up and incorporate nitrogen, phosphorus, manganese potassium, magnesium and other minerals. If these chemicals can be reclaimed economically the proceeds from their sale may well warrant the installation of lights around a sewage oxidation lagoon and may also pay for a certain amount of maintenance which may be necessary for the operation of a lagoon which is loaded at a very high rate.

(20) Ludwig, Harvey F., and Oswald, William J.: "Role of Algae in Sewage Oxidation Ponds", Scientific Monthly, 74: 3-5, 1952.

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VITA

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He received his early education in the Wilkensschule, a public grade school in Heidelberg, Germany. In the Fall of 1941 he entered the Kurfuerst Friedrich Gymnasium, a high school in the above mentioned city, from which he graduated in June, 1951. Afterwards he worked for the United States occupational forces in Germany as Clerk typist and interpreter until March 1952.

On April 1, 1952 he emigrated to the United States where he made his home in Rolla, Missouri. During the summer months of 1952 he worked as a draftsman for the firm of Heagler and Company, Consulting Engineers, Rolla, Missouri. In September, 1952 he entered the Missouri School of Mines and Metallurgy as a freshman in the Civil Engineering Department. In January of 1956 he received his B. S. in C. E. and was appointed an Instructor in Mechanics at the Missouri School of Mines and Metallurgy.

In February, 1956, he started work on an advanced degree in Civil Engineering. Part-time employment during undergraduate school years and summer employment during graduate and undergraduate school years was with Heagler & Company, Consulting Engineers, Rolla, Missouri.

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